

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
 Organization
 International Bureau



(43) International Publication Date
 26 August 2004 (26.08.2004)

PCT

(10) International Publication Number
WO 2004/073077 A1

(51) International Patent Classification⁷: **H01L 41/24**

(21) International Application Number:
 PCT/GB2004/000485

(22) International Filing Date: 9 February 2004 (09.02.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
 0303150.7 12 February 2003 (12.02.2003) GB

(71) Applicant (for all designated States except US): 1...LIM-
 ITED [GB/GB]; St John's Innovation Centre, Cowley
 Road, Cambridge CB4 0WS (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): TOPLISS, Richard
 [GB/GB]; 43 Bishops Road, Trumpington, Cambridge
 CB2 2NQ (GB). RICHARDS, David, Charles, William
 [GB/GB]; 61 Coles Road, Milton, Cambs CB4 6BL (GB).

(74) Agents: MERRYWEATHER, Colin, Henry et al.; J.A.
 Kemp & Co., 14 South Square, Gray's Inn, London WC1R
 5JJ (GB).

(81) Designated States (unless otherwise indicated, for every
 kind of national protection available): AE, AG, AL, AM,
 AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
 CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
 GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE,
 KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD,
 MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG,
 PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM,
 TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM,
 ZW.

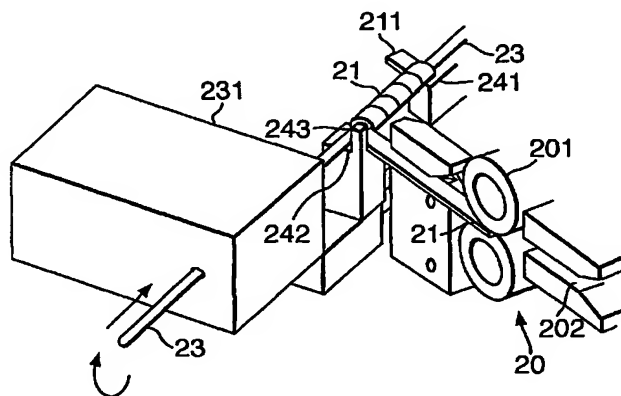
(84) Designated States (unless otherwise indicated, for every
 kind of regional protection available): ARIPO (BW, GH,
 GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),
 Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), Euro-
 pean (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR,
 GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK,
 TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
 ML, MR, NE, SN, TD, TG).

Published:

— with international search report
 — before the expiration of the time limit for amending the
 claims and to be republished in the event of receipt of
 amendments

For two-letter codes and other abbreviations, refer to the "Guid-
 ance Notes on Codes and Abbreviations" appearing at the begin-
 ning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS FOR MANUFACTURING CERAMIC DEVICES



(57) Abstract: An apparatus for manufacturing a ceramic device from tape (21) in a green state comprises a cylindrical rod (23) as a first forming element, a first clamping system (241) for fixing a first end of the tape (21) with respect to the cylindrical rod (23) and a first mechanism (20, 231) for winding the tape (21) around the cylindrical rod (23) to preform the tape (21). The apparatus further comprises a second forming element (33), a second clamping system (351, 352) for fixing at least one end of the pre-formed tape (21) with respect to the second forming element (33), and a second mechanism (331, 351) which winds the pre-formed tape (21) around the second forming element (33).

WO 2004/073077 A1

Method And Apparatus For Manufacturing Ceramic Devices

This invention relates to a method and apparatus for manufacturing curved elements of electro-active material. More particularly, it relates to a method and apparatus for manufacturing electro-active actuators curved around an axis which is
5 itself curved.

Comparably large translation displacements have been recently achieved by using a curved, helical structure of coiled piezoelectric tape in which a multilayer tape is curved helically around an axis which is itself curved. Such devices are found to easily exhibit displacement in the order of millimetres on an active length of the order of
10 centimetres. These structures and variations thereof are described, for example, in WO-01/47041 and in D. H. Pearce et al., Sensors and Actuators A 100 (2002), 281 -286.

These structures are ceramic devices of complex curved shape and are currently manufactured using inefficient low output methods which rely heavily on human labor. Other methods using extrusion processes are described for example in WO-02/103819.
15 However the described process may not be feasible for all configurations of super-helical actuators.

Therefore it is seen as an object of the invention to provide a method and apparatus for manufacturing twice coiled actuators with limited human involvement and using flat ceramic tape as base material.

20 According to an aspect of the invention, there is provided a method of and an apparatus for manufacturing ceramic devices including the steps of transporting ceramic tape in a green state into the proximity of a first forming element; fixing a first end of the tape with respect to the first forming element; moving the tape and first forming element relatively to each other in a motion including simultaneously rotational and translational
25 movements, thus winding the tape around the first forming element; removing the fixing of a first end thereby allowing separation of the tape and first forming element to generate a helically wound pre-formed tape; fixing at least one end of the pre-formed

-2-

tape with respect to a second forming element; and moving the pre-formed tape and second forming element relatively to each other in a motion including at least a rotational movement, thus winding the pre-formed tape around the second forming element.

- 5 The invention preferably includes the step of and devices for moving the tape and the first forming element relatively to each other including the step of continuously pressing during the movement the tape onto the first forming element at a zone where the tape first contacts the first forming element.

- 10 Furthermore the invention preferably includes the step of exerting a force on the edge of the tape at a zone where the tape first contacts the first forming element to prevent slippage of the tape relative to the first forming element.

 The invention preferably includes the step of and devices for closing a second clamping element around the first end of the tape before releasing a first clamping element fixing the tape to the first forming element.

- 15 Preferably, the clamping elements used for gripping the tape or other devices designed to exert pressure directly onto the tape are pneumatically operated or spring-loaded to simulate a "tactile" handling of the tape.

 The invention preferably includes the step of and devices for passing the first forming element along an edge holding back the pre-formed tape.

- 20 Preferably the pre-formed tape is held at both ends using clamping elements with one of the clamping elements fixing one end of the pre-formed tape with respect to the second forming element while the other clamping element performs a rotational movement around the second forming element.

- 25 The invention preferably includes the step of and devices for removing the fixing with respect to the second forming element and transferring the wound pre-formed tape onto a support structure; and placing the support structure into heated environment for drying and/or sintering.

-3-

The present invention is particularly advantageous used to manufacture twice-coiled helices, particularly twice-coiled actuators of piezoelectric material.

These and other aspects of inventions will be apparent from the following detailed description of non-limitative examples making reference to the following
5 drawings.

In the drawings:

FIG. 1 is a perspective view of a twice-coiled actuator as known;

FIG. 2 illustrates a first forming step in accordance with an example of the present invention;

10 FIG. 3A illustrates a step of releasing pre-formed tape from a first forming element;

FIG. 3B illustrates a second forming step in accordance with an example of the present invention; and

FIG. 4 illustrates the transfer of formed tape onto a support structure for drying.

15 FIG. 1 shows a known actuator 10 of the type described in WO-01/47041 and Sensors and Actuators A 100 (2002), 281 -286.

The actuator 10 has a curved portion 12 of multi-layer tape 11, for example of a bimorph construction, that is wound helically around a first axis 13 referred to as the minor axis. For illustration, the minor axis is shown as a dashed line 13 in FIG. 1. The
20 helically wound portion is further coiled into a secondary winding of about three quarters of a complete turn. The axis 14 of this secondary winding is referred to as the major axis and shown as a small dashed circle 14 with a central solid point again to facilitate description and illustration. The first winding is known as the primary winding or primary helix. The secondary winding could be any curve and could exceed one turn
25 and form a spiral or secondary helix. It is therefore usually referred to as secondary curve. The tape is arranged on actuation to bend around the minor axis 13. Due to the helical curve around the minor axis, such bending is concomitant with twisting of the

-4-

actuator 10 around the minor axis. Due to the curve around the major axis 14, such twisting is concomitant with relative displacement of the ends 111, 112 of the actuator 10. When used as an actuator, one end 111 of the tape 11 may be fixed to a moveable object (not shown) while the other end 112 of the tape 11 may be mounted onto a base plate 15.

The manufacture of the actuator 10 from a precursor ceramic tape is a very complex task usually performed by manual labor. It involves the steps of slowly winding a helix of the tape around a cylindrical rod and, and after carefully removing the rod, placing the helix into a "sagger" that supports the helix in its coiled form during subsequent drying until the ceramic tape is sufficiently stiff to support its own weight. The coiled helix is then burned to remove binder and other organic components and sintered to form the ceramic actuator.

While the above steps can be performed manually, the process does not readily lend itself for automation. The properties of the precursor ceramic tape are such that, though pliable, it slackens readily and is unable to support its own weight.

Referring now to FIG. 2A, there is shown a conveyor system 20 that transports a strip of precursor ceramic tape 21 to a cylindrical rod 23. The conveyor system 20 includes rollers 201 and support surfaces 202 that guide the strip 21 close to the former 23. A smoothly contoured surface 204 directs the tape 21 under the rod 23. When positioned at the conveyor system 20, an end block 231 supports the distal end of the rod to prevent it from bending and provides a rotary drive for rotating the rod 23 and a linear drive for translating the rod 23. After a tap 211 of sufficient length has passed a first pneumatically operated clamp 241 closes and fixes the tape 21 against the rod 23. Then the rod 23 is rotated and translated as indicated, while more tape is pushed through the conveyor system 20. Thus the end block 23 and the conveyor system 20 act as the a first mechanism for moving the tape 21 and the rod 23 relatively to each other.

The rod 23 acts as a primary or first former. Its diameter is chosen such that it

-5-

matches the inner diameter of the primary helix.

The conveyor and the axis of the rod form an acute angle to feed tape at this angle onto the rod. As the strip is pushed by the conveyor across the rod 23, the rotation of the rod 23 causes the strip 21 to be wound around it. Simultaneously with the rotation, 5 the rod 23 is moved in direction of its axis. Both motions are synchronized such that the tape is wound around the rod in a helical manner.

In FIG. 2B, the winding process of FIG. 2A is shown at a later stage with the tape 21 being wound around the former 23 for approximately half of its length. As the first clamp 241 is retracted from the conveyor system 20, a second spring-loaded clamp 10 242 is brought from below into contact with the tape. The second clamp has a slightly concave surface with a stop pin 243. The concave surface maintains pressure on the tape while the stop pin 243 prevents the slippage of tape along the rotating rod 23, thus ensuring that the helix remains tightly wound.

After the strip of tape 21 is fully wound around the primary former 23, the 15 second end of the tape forms a second short stub (not shown) similar to the stub 211. The rod 23 is then moved by the linear drive of the block 231 to a second forming element. During the transport both clamps 241, 242 remain in place.

At the location of the second former 33, two clamps 351, 352 grip the tape at the stubs 211 as illustrated in FIG. 3A. The previous clamps 241, 242 are released and the 20 forming rod 23 is moved in axial direction in sliding contact with an edge 353. The first former 23 is shown as a dashed outline. The first clamp 351 is fixed to the mounting block 331 that carries the second former 33. It pushes the stub 211 at one end of the tape 21 against the outer edge of the inner cylinder 332 of the second former 33. The combined clamp 351 and second former 33 are simultaneously rotated around the center 25 axis of the cylindrical second former 33 and moved towards the second clamp 352 that rests immobile during this movement. Thus, the first clamp 351 and the second clamp 352 form the a second mechanism for moving said pre-formed tape and second forming

-6-

element relatively to each other. As the second former 33 approaches the second clamp, more of the rod 23 slides over an edge 353 and more windings are pushed from the distal end of the rod. The windings are wound around the inner cylinder 332 of the rotating secondary former 33 until the tape is completely stripped of the primary former. At this stage, which is illustrated in FIG. 3B, the pre-formed tape 21 is wound completely
5 around the inner cylinder 332 of second former 33 and held in place by the two clamps 351, 352.

The inner cylinder 332 is spring-mounted within a bore of an outer cylinder 333 of the second former 33, such that pressure on the front face of the inner cylinder causes
10 it to retract into the bore while the advancing sleeve of the outer cylinder pushes the wound tape 21 from the former.

At this stage of the process the twice-coiled actuator of FIG. 1 is completed in its "green" state. However to stabilize the structure, the tape 21 has to be at least dried. To free the second former 33, the wound helix is transferred into a tray or array for further
15 handling off-line .

In FIG. 4, the secondary former 33 is shown approaching a array 40 of sagger 41. As the secondary former meets a sagger 41, the front face of its inner cylinder 332 (shown in FIG. 3 above) engages a matching cylinder 431 within a recess area 432 of a sagger 41. As the secondary former moves closer to a sagger, the spring-loaded inner
20 cylinder 332 remains stationary and the outer ring 333 pushes the twice-coiled helix into the recess 432 of the sagger. The clamps that grip the stubs or ends of the tape open to release the helix. The outer boundary of the recess area 432 has a diameter that closely matches the nominal outer diameter of the major helix of the actuator. The edges of the boundary of the recess area are contoured or chamfered to assist the placing of the tape
25 into the sagger. The sagger array 40 filled with fully formed green tape is then placed in a heated environment for drying and prepared for further processing stages such as sintering in an oven.

-7-

The various clamping devices described above are using pneumatically operated actuators commercially available for example from Festo. Commercially available DC servo motors are used to generate other movements of the components. All components are under the control of a computer program stored in and executed from an Intel
5 processor based workstation.

Variations of the above example are readily within the scope of a skilled person. It is for example feasible to design the forming elements in a segmented manner to alter their diameter and hence the dimensions of the actuator. It is also possible to replace the second forming element with a removable sagger and thus wind the pre-formed tape
10 directly onto the sagger.

Claims

1. A method of manufacturing a ceramic device comprising:
transporting ceramic tape in a green state into the proximity of a first forming
5 element;
fixing a first end of said tape with respect to said first forming element;
moving said tape and first forming element relatively to each other in a motion
including simultaneously rotational and translational movements, thus winding said tape
around said first forming element;
10 removing said fixing of a first end thereby allowing separation of said tape and
first forming element to generate a helically wound pre-formed tape;
fixing at least one end of said pre-formed tape with respect to a second forming
element; and
moving said pre-formed tape and second forming element relatively to each other
15 in a motion including at least a rotational movement, thus winding said pre-formed tape
around said second forming element.
2. The method of claim 1, further comprising, during the step of moving said tape
and first forming element relatively to each other, continuously pressing said tape onto
20 said first forming element at a zone where said tape first contacts said first forming
element.
3. The method of claim 2, further comprising, during the step of moving said tape
and first forming element relatively to each other, exerting a force on the edge of the
25 tape at a zone where said tape first contacts the first forming element to prevent slippage
of said tape relative to said first forming element.

-9-

4. The method of any one of the preceding claims, further comprising, between the step of moving said tape and first forming element relatively to each other and the step of removing said fixing of a first end, closing a second clamping element around the first end of the tape.

5

5. The method of any one of the preceding claims, wherein the step of separating said tape and first forming element comprises moving the first forming element relatively to an edge holding back the pre-formed tape.

10 6. The method of any one of the preceding claims, wherein, during the step of moving said pre-formed tape and second forming element relatively to each other, the pre-formed tape is held at both ends using clamping elements, one of said clamping elements fixing one end of said pre-formed tape with respect to the second forming element, the other clamping element performing a relative rotational movement around
15 said second forming element.

7. The method of any one of the preceding claims, further comprising the steps of removing the fixing with respect to the second forming element and transferring the wound pre-formed tape onto a support structure; and
20 placing said support structure into environment for drying.

8. The method of any one of the preceding claims, wherein the tape is handled by pneumatically operated devices.

25 9. The method of any one of the preceding claims, wherein the step of moving said tape and first forming element relatively to each other comprises rotating the first forming element and translating the unwound portion of the tape towards the first

-10-

forming element.

10. The method of claim 9, wherein the step of moving said tape and first forming element relatively to each other further comprises translating the first forming element
5 along an axis about which the tape is wound.

11. The method of any one of the preceding claims, wherein, in the step of moving said tape and first forming element relatively to each other, the tape is wound helically around the first forming element.
10

12. The method of any one of the preceding claims, wherein the first forming element is cylindrical.

13. The method of any one of the preceding claims, wherein the tape comprises
15 layers of electro-active material.

14. An apparatus for manufacturing a ceramic device from tape in a green state, the apparatus comprising
a first forming element;
20 a first clamping system for fixing a first end of said tape with respect to said first forming element;
a first mechanism for moving said tape and first forming element relatively to each other in a motion including simultaneously rotational and translational movements, thus winding said tape around said first forming element to form a preformed tape;
25 a second forming element;
a second clamping system for fixing at least one end of said pre-formed tape with respect to said second forming element; and

-11-

a second mechanism for moving said pre-formed tape and second forming element relatively to each other in a motion including at least a rotational movement, thus winding said pre-formed tape around said second forming element.

5 15. The apparatus of claim 14, wherein the first clamping system includes a spring-loaded surface that in operation continuously presses the tape onto said first forming element at a zone where said tape first contacts said first forming element.

10 16. The apparatus of claim 15, wherein the spring-loaded surface is combined with a force-transmitting member adapted to contact the edge of the tape at a zone where said tape first contacts the first forming element to prevent slippage of said tape relative to said first forming element.

15 17. The apparatus of any one of claims 14 to 16, further comprising a stripping edge making contact to the first forming element to separate said first forming element and the pre-formed tape.

20 18. The apparatus of any one of claims 14 to 17, wherein the second clamping system includes a first clamping element for fixing a first end of the tape to the second forming element and a second clamping element for fixing the other end of the tape, the second mechanism being arranged to relatively rotate the second clamping element around said second forming element.

25 19. The apparatus of claim 18, further comprising one or more saggers having recesses adapted to support the formed tape during drying.

20. The apparatus of any one of claims 14 to 19, wherein the clamping devices are

-12-

pneumatically operated.

21. The apparatus of any one of claims 14 to 20, wherein the first forming element is a cylindrical rod.

5

22. The apparatus of any one of claims 14 to 21, wherein the first mechanism comprises a rotary drive arranged to rotate the first forming member and a conveyor system arranged to translate the tape towards the first forming member.

10 23. The apparatus of claim 22, wherein the first mechanism further comprises a linear drive arranged to translate the first forming member along an axis about which the tape is wound.

15 24. A ceramic structure made using methods or apparatus in accordance with any of preceding claims.

25. The ceramic structure of claim 24 being an electro-active ceramic structure.

1/3

Fig.1.
(Prior Art)

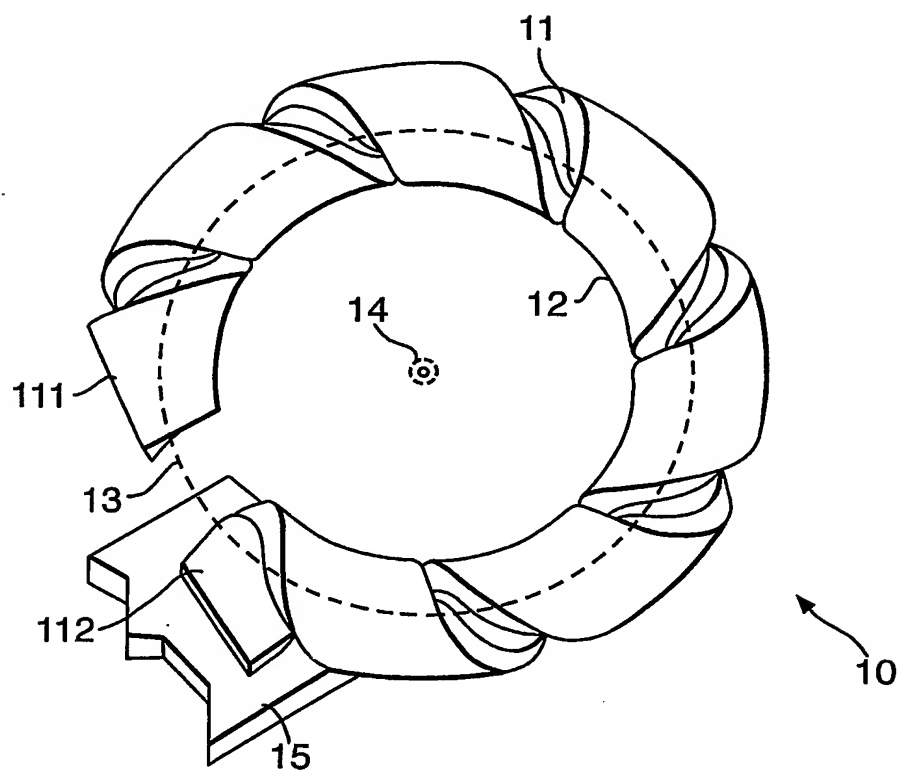


Fig.2A

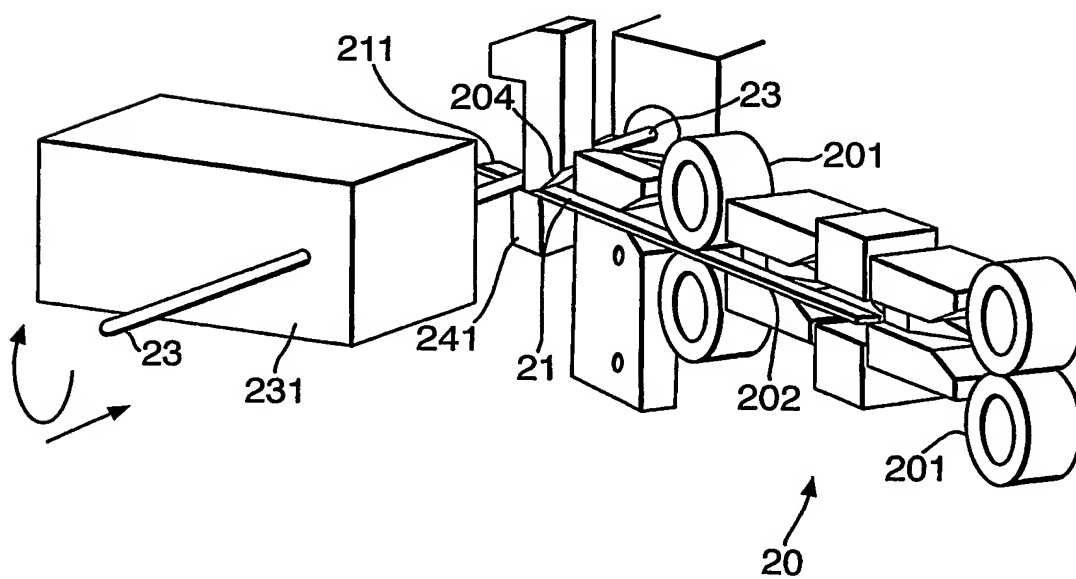


Fig.2B.

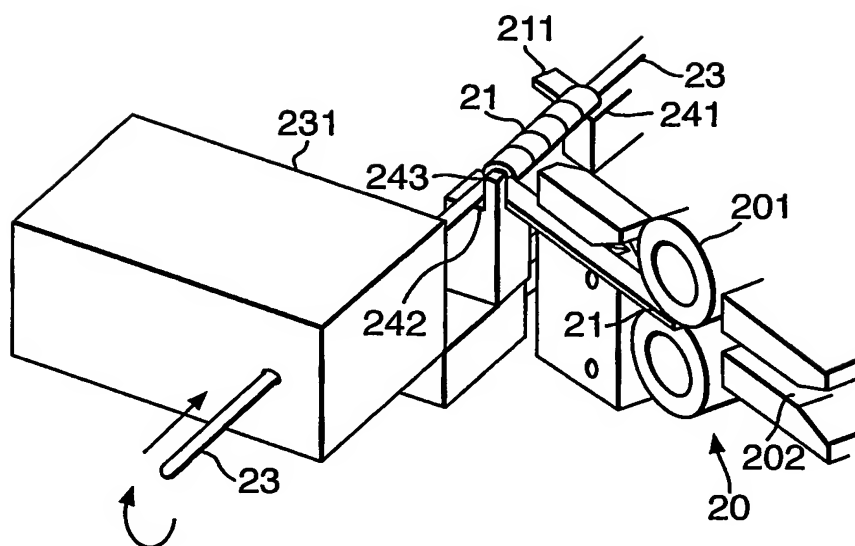
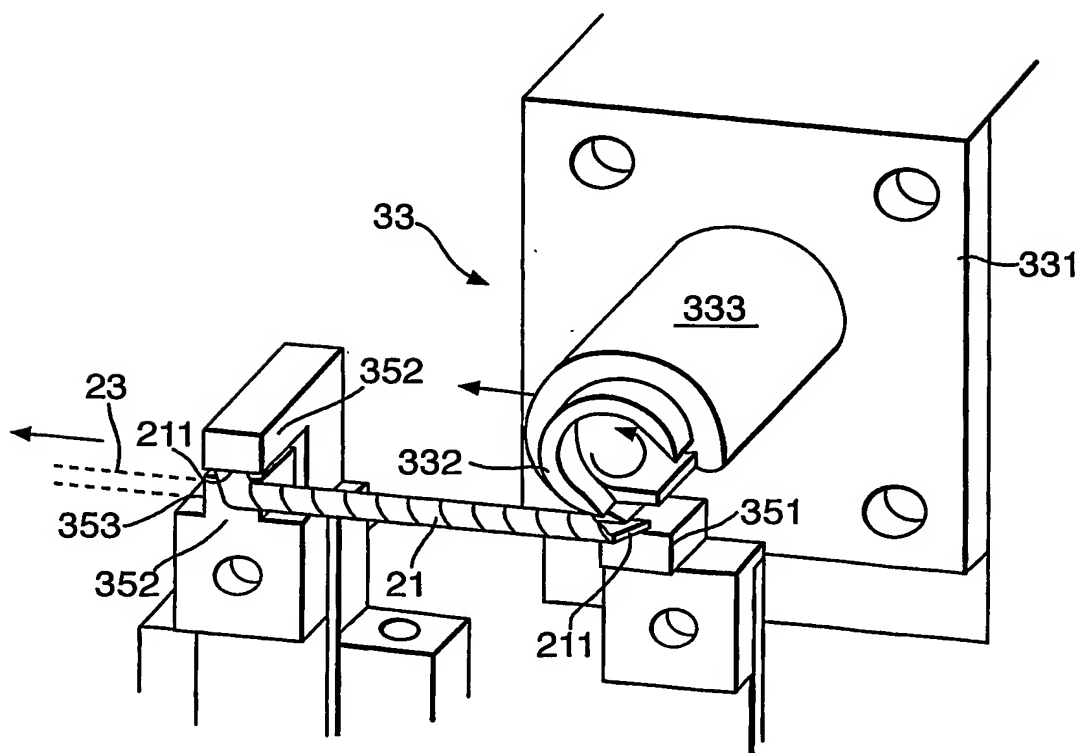


Fig.3A.



3/3

Fig.3B.

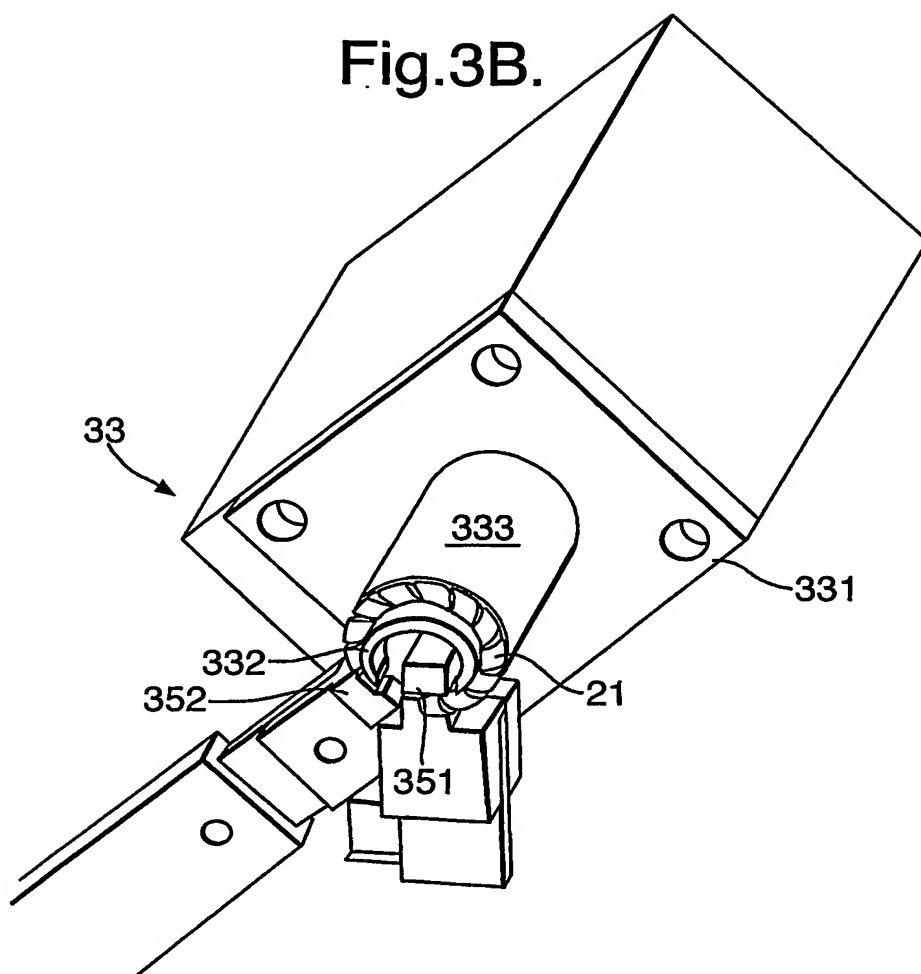
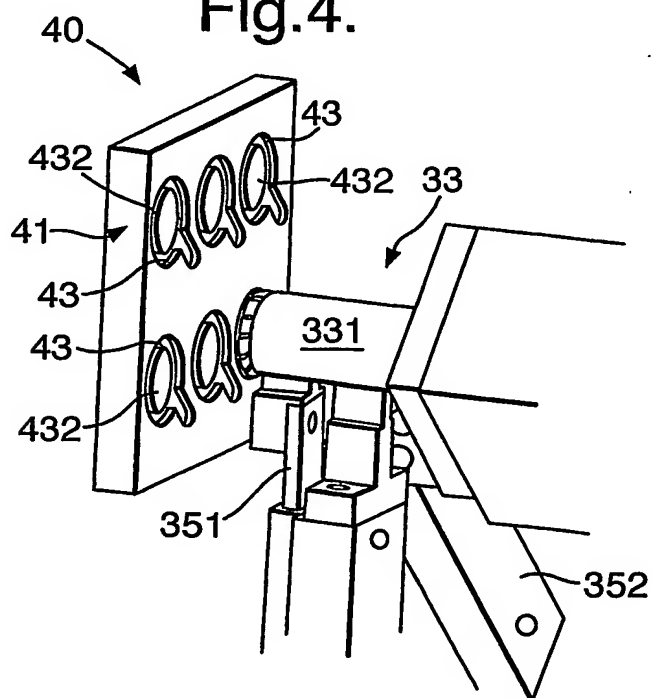


Fig.4.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/000485

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L41/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L B21F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 01/47041 A (LENEL URSULA RUTH ; SHEPHERD MARK RICHARD (GB); 1 IPR LTD (GB); HOOLEY) 28 June 2001 (2001-06-28) cited in the application page 26, line 28 - page 27, line 3 page 30, line 31 - page 34, line 19 figures 26-28	1-25
A	EP 0 372 872 A (TEXAS INSTRUMENTS INC) 13 June 1990 (1990-06-13) the whole document	1, 14
A	US 6 464 918 B1 (GROB SIEGFRIED ET AL) 15 October 2002 (2002-10-15) column 3, line 46 - line 56	1, 14

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

*** Special categories of cited documents :**

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

16 July 2004

Date of mailing of the international search report

23/07/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Meul, H

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB2004/000485

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0147041	A	28-06-2001	AU 2016501 A	03-07-2001
			AU 2016801 A	03-07-2001
			CN 1434985 T	06-08-2003
			EP 1240676 A2	18-09-2002
			WO 0147041 A2	28-06-2001
			WO 0147318 A2	28-06-2001
			GB 2364169 A , B	16-01-2002
			GB 2376834 A , B	24-12-2002
			JP 2003518752 T	10-06-2003
			US 2004017129 A1	29-01-2004
			US 2003095678 A1	22-05-2003
EP 0372872	A	13-06-1990	US 4920624 A	01-05-1990
			DE 68914109 D1	28-04-1994
			DE 68914109 T2	07-07-1994
			EP 0372872 A2	13-06-1990
			JP 2192842 A	30-07-1990
US 6464918	B1	15-10-2002	DE 19839457 A1	09-03-2000
			AT 202258 T	15-06-2001
			DE 59900118 D1	19-07-2001
			EP 0987923 A1	22-03-2000
			ES 2158717 T3	01-09-2001
			JP 2000077166 A	14-03-2000